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Title: On-Board Autonomous Determination of Spacecraft Attitude
Maneuvers Using Genetic Algorithms

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Abstract

A key enabling technology that leads to greater spacecraft autonomy is the capability to autonomously and optimally slew the spacecraft from and to different attitudes while operating under a number of celestial and dynamic constraints. Constraints may include the protection of sensitive science or stellar reference instruments and radiators from direct exposure to the sun and other bright bodies as well as limitations on the allowable spacecraft turn acceleration and rate.

The task of finding an attitude trajectory that meets all the constraints is a formidable one, and is considered to be computationally hard in many instances. This is in particular true for orbiting or fly-by spacecraft where the constraints and initial and final conditions are of time-varying nature. Because of this difficulty, attitude maneuver determination has traditionally been done on the ground, with only a few spacecraft partially addressing this task in flight.

The Topex Autonomous Maneuver Experiment (TAME) was a first step in implementing an autonomous attitude planner for an earth orbiting spacecraft. The attitude planner used was based on a simple and undirected trial-and-error search and didn't incorporate the time varying nature of the problem per se and therefore lacked the computational efficiency and scalability necessary to attack more complex problems. The attitude planner used on DS-1 is based on a heuristic constraint checker that detects constraint violations and attempts to 'circumnavigate' them. However, due to its short replanning time-horizon, the constraint monitor has no knowledge of whether any other constraints are being violated along its replanned trajectory. Thus, it does not incorporate the time-varying constraints into the actual re-planning task *proactively*, and lacks computational efficiency and may expend a large amount of fuel before achieving the goal attitude.

This paper presents an approach that addresses these short comings and is computationally tractable enough to be executed on-board a spacecraft. The approach is based on incorporating the constraints into the cost function and using a Genetic Algorithm to iteratively search for and optimize the solution. A particular solution is penalized if it causes the spacecraft to violate a constraint thus ensuring that the algorithms is searching for the solution with no or the least constraint violations. The Genetic Algorithm is searching for improved solutions by using a 'survival of the fittest' strategy, i.e. by searching in the 'vicinity' of good solutions for better ones. This results in a directed random search that explores a large part of the solution space while maintaining the knowledge of good solutions from iteration to iteration.

While the search for the optimal solution is inherent part of the search process, it is not the primary purpose. Rather, the search to obtain a *feasible* solution in a *reasonable* time is the driving force behind the design of the algorithm. To this end, a number of simplifying assumptions have been made to reduce the problem to be computationally tractable and at the same time maintain the validity of the solutions found. Hence, optimality is traded with computational complexity. A solution obtained this way may be used as is or as an initial solution to initialize additional deterministic optimization algorithms.

A number of simulations are presented in the paper including the case examples of a generic Europa Orbiter spacecraft in cruise as well as in orbit around Europa. The simulations are run in Matlab using m-files. For the cases investigated, the search times for constraint free solutions are typically on the order of minutes, thus demonstrating the viability of the

presented approach. Moreover, in a real-time environment, a significant faster execution time can be expected.

The results are applicable to all future deep space missions such as Europa Orbiter where spacecraft distance precludes ground intervention during critical maneuvers or unforeseen in-situ science opportunities. In addition, onboard autonomous attitude planning greatly facilitates navigation and science observation planning, benefiting thus all missions to planet Earth as well.